DESIGN OF MICROSTRIP ANTENNA CONFORMABLE TO BOTH PLANAR AND CYLINDRICAL SURFACES FOR AIRCRAFT SYSTEMS

Synopsis of the Thesis

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SYNOPSIS

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Antenna represents the interface between the transmitter and the receiver in a free space communication system. Advancement in the communication, navigation and electronics warfare systems has resulted in the design and development of antennas using modern design and cutting edge technologies. With the advancement of latest fighter aircraft designs, new approaches for the integration of antenna systems have evolved. One important aspect of the design of antennas for the future fighter aircraft systems has been the ability to fend for itself in a rapidly changing threat scenario. Optimizing the design of the antenna characteristics will lead to considerable improvements in the overall system performance like better accuracy, superior aerodynamics, and lighter weight, etc. Efficient design of aircraft systems using structurally integrated antenna systems will be capable of multi role operation. These designs aim towards tackling of the threat, dynamically under Electronic Attack.

It is well known that a frequency agile patch antenna will foil and circumvent the detection of the actual operating frequency by the enemy and prevent the jamming of signals. An attempt has been made here to design such a reconfigurable patch antenna. The design employs multidielectric layers of substrate and a superstrate (cover) layer of dielectric placed directly on the metallic patch on the surface of the aircraft.

Impedance Bandwidth in terms of VSWR$\leq$ 2, an important characteristic of patch antennas is also significantly improved by using the multilayer dielectric configuration. This antenna can form part of a specific high-performance airborne system with applications in the realization of frequency hopping radar.

For large angular coverage in the azimuthal plane, low profile conformal arrays of rectangular antennas are mounted on singly curved cylindrical surface. The singly curved surface forms as an approximation of the shape of an aircraft wing, fuselage or external pods. Such a design will

facilitate the use of antenna in defence applications in radar and communication systems to avoid detection by enemy.

This thesis is therefore mainly devoted to design of frequency agile antennas conformable to both planar and cylindrical surfaces of airborne systems and facilitates specific operational requirements.

SCOPE OF THE THESIS

The thesis is divided into seven chapters. The first chapter is devoted to introductory overview. In the second and third chapters design of planar antenna array along with effect of mutual coupling and the multidielectric layer planar antennas with superstrate (cover) layer are discussed. Subsequent chapters deal with bandwidth enhancement and frequency agility of multi-dielectric antenna with superstrate layer and necessity of conformal antennas /conformal arrays for defence applications that meet the shape requirements of the aerodynamic structure.

CHAPTER 1:

In Chapter 1 we deal with the historical background of microstrip antennas and their suitability for applications in aircraft and missile systems. The theory of operation of patch antenna along with its feeding techniques is discussed in this chapter. The design of antenna array, along with the design of multidielectric layer antenna has been studied in detail. The effect of mutual coupling in microstrip antenna array is included in this chapter. Necessity of conformal antennas and conformal arrays vs. planar arrays are also discussed. To further its claim for airborne application selection, necessary antenna characteristic considered essential is its mechanical robustness to withstand shock and vibration and a highly reliable structure.

CHAPTER 2:

Chapter 2 presents the basic characteristics and structure of microstrip antenna and an array of such antennas. In this chapter we have discussed the modeling and the performance analysis of a 2×2 symmetrical four element and a 2×3 asymmetrical six element patch array. Further, it has been shown that for any planar array configuration optimized antenna characteristics can be obtained, depending upon the variation of the inter element spacing. Configurations of 2×2 and

2×3 patch arrays have been analyzed and an optimum frequency range of the patch antenna array has been arrived at. It is concluded that for any planar array configuration, optimized antenna characteristics can be obtained, depending upon element spacing. The effects of surface waves and mutual coupling is minimized by optimizing the inter element spacing in both the planes. The antenna provides frequency close to the designed operating frequency with an acceptable Directivity and Gain.

Study of antenna parameters has been carried out in *E*-plane with an inter element spacing fixed at 0.5λ. It has been shown that with variation of element spacing in the *H*-plane the return loss is affected due to mutual coupling [1]. Better performance at frequency closely spacing the patch antenna in the array shifts the input impedance at resonance to a lower value which in turn affects the return loss.

An optimum design in two dimensional planes with linear spacing in *H*- plane at 0.55 λ and in *E*-plane at 0.5 λ and vice versa, is arrived at. It is found that at this spacing the performance of the antenna is closest to the designed operating frequency with a good return loss. The Directivity, Antenna Gain, Efficiency, Power Radiated and the Radiation Pattern by the patch array achieved as required for the system [2].

Reduction in inter element spacing in *H*-plane results in a shift of resonance frequency f_r. This is attributed to the parallel line which reduces the effective permittivity and as a result resonance frequency f_r increases. It has been observed that with inter element spacing in *H*-plane >0.55λ coupling affects the performance due to combined effect of surface and space waves. Further it has been concluded that the coupling between antenna patches is of significance in arrays where the separation between patches is of the order of a wave length λ or less.

CHAPTER 3:

Chapter 3 presents the conformal mapping technique for the design of multidielectric layer antenna with improved accuracy in performance. Algorithm has been developed to design the antenna that eliminates the effects of inaccuracies that can have a compounding effect from the design stage to the fabrication of the multidielectric layer antenna. Multidielectric antenna designed using the *suggested* algorithm to operate in GHz frequency range is seen to have a drift

in frequency that is as low as 1 MHz Therefore in view of inherent narrow bandwidth of the patch antennas, the antennas with multidielectric layered structure is designed to ensure that there is minimum drift in the resonant frequency [3].

Superstrate dielectric layer called the cover layer has been used since there is a need to protect the antenna integrated to aircraft structure. It is concluded that with a proper choice of the thickness of the substrate and the superstrate (cover) layer a significant increase in gain for practical applications can be achieved. The addition of a cover layer over the substrate results in a structural resonance referred to as the resonance gain method and has been included as a part of the design. Results obtained from the analysis of multidielectric layer antenna with superstrate layer shows significant changes in its properties like resonance frequency, directivity, gain and bandwidth which alters the system performance.

Operational requirement related to fighter aircraft demands electronic systems to function in X band. Hence the design of the antenna operating at 10 GHz frequency has been considered. Analysis on changes in the characteristics of substrate and superstrate and its effects on antenna parameters specifically with respect to the change in thickness of the superstrate layer have also been analyzed.

CHAPTER 4:

One of the important characteristics of microstrip patch antennas is its Impedance Bandwidth. It is specified in terms of return loss (S_{11}) or VSWR$\leq$ 2. Impedance Bandwidth can be significantly improved by using multilayer dielectric configuration. To achieve this, the emphasis is mainly laid on bandwidth enhancement techniques of a multilayer patch antenna, designed for X-band applications. This chapter presents the antenna losses containment in the design of microstrip patch antenna by controlling of the quality factors. While ensuring desired radiation pattern, the design provides an improved bandwidth of the patch antenna. The design also considers the effect of the cover layer on the impedance matching, Q factor and hence bandwidth and frequency.

The results presented in the chapter are based on the Method of Moments and Finite Difference Time Domain approach. The procedure for bandwidth enhancement proposed in this chapter

emphasizes the importance of quality factor optimization as a parameter to realize broadband communication. After a series of analytical and graphical study of a multilayer microstrip antenna an Impedance Bandwidth of 5.8% has been obtained with low permittivity substrates. The bandwidth further improves to 7.5% by using a cover layer which is an improvement over a conventional multidielectric layer antenna by approximately 30% [5]. Realization of improved bandwidth with minimization of surface wave losses is due to contribution of offset impedance matching employed in the feeding technique.

CHAPTER 5:

Chapter 5 addresses the problem related to future aircraft systems to shield it from rapidly changing threat situations. Design of antenna has been carried out to overcome the threat in the form of Electronic Attack. Airborne antenna systems have been designed to be reconfigurable and to overcome intentional and unintentional electromagnetic disturbances. Therefore the redesigning and construction of the microstrip patch antenna has been carried out at different frequencies keeping all other parameters constant and changing the permittivity of the cover layer. To vary the frequency of resonance, the results is analogous to one in which the dimensions of the patch is changed. The results with variations in the dimensions of the patch with the permittivity of the cover layer are tabulated and analyzed. It is also ensured that the cover layer does not adversely affect the performance of the antenna.

By choosing the cover layer parameters appropriately a significant increase in antenna gain and efficiency is achieved, enabling the cover layer to act as the part of the antenna. This facilitates the use of the antenna in defence applications to avoid detection by enemy. This chapter therefore presents a novel design of frequency agile reconfigurable multidielectric microstrip patch antenna with a cover layer placed directly on the surface of the aircraft.

Such a design can be suitably utilized for realization of frequency hopping specifically in high-performance airborne applications. Most importantly cover layer considered is electrically conductive foil tape with adhesive applied to one surface is used to create the radiating element and the ground plane. The antenna structure can then be mounted on the desired surface by means of structural tape adhesives. The proposed design achieves frequency agility ranging from

0.5% to 18% with centre frequency at 2.718 GHz [4].

CHAPTER 6:

Chapter 6 presents the necessity of conformal microstrip antenna and arrays to suit the curved aerodynamic surfaces of a supersonic aircraft or missiles and modeled approximately in the shape of a cylinder. This chapter covers conformal mapping of antenna and arrays mounted on a cylinder to a planar surface and a simulation of microstrip patch antenna and arrays on planar surface, the design and analysis of the effect of mutual coupling in both planar and cylindrical surfaces along with a full-wave analysis of cylindrical microstrip using moment-method.

The study of the effect of variation of the resonant frequency with the variation in the radius of the cylinder of the rectangular microstrip patch, excited in the TM_{10} mode has been carried out. Variation in the resonant frequency for cylinders of larger radius has been studied. Conformal cylindrical patch antenna transformed to planar patch is obtained utilizing the transformation technique. Since the resonant frequency is dependent on the chosen length of the patch, a curve plotted to compare resonant frequency changes in the cylindrical patch antenna due to change in the radius of the cylinder. The result is obtained by an extrapolation of the change in the frequency due to changes in the length of the transformed planar antenna. Based on a set of data which relates to the variation in resonant frequency of the transformed planar patch in comparison with the patch on the curved cylindrical surface, demonstrates that this assumption holds good for the height *h* being small compared to the surface curvature. Based on a set of data which relates to the variation in resonant frequency of the transformed planar patch in comparison with the patch on the curved cylindrical surface, demonstrates that this assumption holds good for the height *h* being small compared to the surface curvature. The curve shows the variation of the ratios $f_{conformal}/f_{planar}$ versus Cylindrical Radius /Transformed Length and an empirical relation is derived from there.

Two element microstrip patch antenna array with a corporate feeding network on a cylindrical surface is transformed using conformal mapping technique. The effect of mutual coupling and the curvature is also incorporated in the transformation of the cylindrical microstrip array to a planar microstrip array. Comparison of plots for both single element and two element microstrip

antenna array led to inference that due to effect of curvature and mutual coupling on account of inter element spacing and increase in array size results in significant changes in frequency in conformal vis-à-vis planar antenna. In the analysis it is necessary to consider the effect of mutual coupling on the frequency and antenna parameters when inter element spacing in both *H* and *E*-plane is changed. Designed Antenna array resonates at 10 GHz, however the resonating frequency is seen changing due to mutual coupling and at 0.6 λ spacing it is resonating closest to the designed frequency. Effect of mutual coupling because of the variation in the inter element spacing on the antenna parameters like the gain, the directivity, the efficiency and the return loss. While considering the effect on the above stated parameters the shift in the resonant frequency must be kept in mind. It is observed that at 0.7 λ all antenna parameters provide best results except poor return loss with considerable shift in resonant frequency from the designed frequency of 10 GHz.

A comparative study of the performance of a planar array with an array conformal to cylindrical surface has been discussed. Four element transformed microstrip patch antenna has been considered for comparison. Antenna parameters for variation in inter element spacing in *E* and *H*- plane has been collated.

Full Wave Analysis involving study of the current distribution on the patch, expresses the current in terms of Basis functions. The current distribution is plotted along the centre lines of the patch. Using Basis function, both triangular and impulse function for exciting the cylindrical surface, radiation pattern in both θ and φ plane are shown viz. E_θ and E_φ respectively are obtained. Excitation of cylindrical patch using Basis function with impulse function in φ plane with singularity and cosine function in *z* plane again with singularity, the corresponding field plots E_θ and E_φ are shown. In the φ plane the plot is identical as without edge singularity, however in the θ plane, the radiation pattern shows significant side lobe unlike without singularity has directional beam which is symmetrical in all the four quadrants. In both the *z* and φ planes the singularity contributes to change in the field pattern.

CHAPTER 7:

Chapter 7 deals with the main contributions and results of the thesis and scope of further work.

MAIN CONTRIBUTIONS AND RESULTS:

The thesis deals with the design of frequency agile microstrip antennas configurable to planar and non planar surfaces of the airborne systems. It is shown that the effects of surface waves and mutual coupling can be minimized by optimizing the inter element spacing in both the planes of a planar array. The performance of the antenna is close to the designed operating frequency with an acceptable Directivity and Gain.

Improved accuracy is obtained in the performance of a multidielectric layer antenna having a superstrate layer over the patch while using conformal mapping techniques. The design of multidielectric layer antenna with a superstrate layer eliminates the effects of inaccuracies that can have a compounding effect from the design stage to its fabrication. The process has been successfully tested on both thin and thick dielectric superstrates having low permittivity. The antenna designed for given resonant frequency has been observed to be in correspondence to the patch dimension with a high accuracy. The graphical plots without and with, thin/thick, superstrate layer (low/high permittivity) for a multilayer microstrip antenna can be used to predict the antenna parameters including resonant frequency, return loss, power radiated, directivity and gain.

The thesis discusses the effect of cover layer on impedance matching, Q factor and hence bandwidth and frequency correction. The Method of Moments and Finite Difference Time Domain approach have been used for computation of the results.

It has been established that with appropriate choice of the parameters of the cover layer there has been a significant increase in the gain and efficiency of the antenna. This facilitates the use of the antenna in defence applications where avoiding detection by the enemy is of paramount importance. If the enemy is able to detect the presence of the aircraft or the missile the particular operating frequency of the antenna can be switched to another frequency. This would prevent the jamming of signals and can be achieved just by replacing the original cover layer by a new cover layer with different permittivity.

Microstrip antenna and arrays conformal to cylindrical surface have been analyzed using full wave analysis. The focus in the design has been on the mutual coupling and its influence on the

radiation characteristics. Mutual coupling in arrays gives rise to deviations in antenna patterns compared with those of corresponding isolated elements. Dual patch microstrip elements, fed by coaxial probes, have been used for these investigations. A comparison is made between isolated conformal microstrip antennas and array-embedded conformal antennas.

Evaluation of reflection and surface wave losses for low permittivity substrate based on FDTD analysis has been carried out by using MATLAB. Impedance Bandwidth enhancement, which is an important characteristic of microstrip antennas, can be significantly improved by using multilayer dielectric configuration. Main emphasis has therefore been laid on bandwidth enhancement of a multilayer patch antenna. The cover layer apart from shielding is utilized to make the antenna reconfigurable and hence frequency agile.

SCOPE OF FURTHER WORK

New approaches for the development of new technologies and integration of antenna systems to the fighter aircraft and missiles need to be evolved. Currently the challenges are the design of antennas conforming to the desired shape of the parent body viz. aircraft or missiles. Conformal antennas can be designed in almost any geometry, although the main structure investigated here is cylindrical. The design of spherical and conical microstrip antennas conforming to the nose cone and the canopy structures respectively can be done similarly.

RESEARCH PAPER CONTRIBUTIONS IN THE THESIS

International Conference:

[1] Samir Dev Gupta* and Rahul, *"Optimization of Planar Microstrip Patch Antenna Designed for Lower S-Band",* Eleventh URSI Commission F Triennial Open Symposium on Radio Wave Propagation and Remote Sensing, at Rio de Janeiro, Brazil, pp. 350-356, Oct. 30 to Nov. 02, 2007.

[2] Samir Dev Gupta* and Rahul *"Design & Optimization of Planar Microstrip Patch Antenna Array Operating at Lower S-Band based on Analysis in both H and E Plane",* 11th International Symposium on Microwave and Optical Technology (ISMOT 2007) Italy, at Monte Porzio Catone, Roma – ITALY, pp 769-773, Dec. 17-21, 2007.

International Journal:

[3] Samir Dev Gupta*, Anvesh Garg and Anurag P. Saran, *"Improvement in Accuracy for Design of Multidielectric Layers Microstrip Patch Antenna"*, International Journal of Microwave and Optical Technology(IJMOT), vol.3, No.5, pp 498-504, Nov. 2008.

[4] Samir Dev Gupta*, M.C. Srivastava, *"Design of Frequency Agile Multidielectric Microstrip Antenna for Airborne Applications"*, International Journal of Microwave and Optical Technology(IJMOT), vol.5, No.5, pp 257-266, Sep. 2010.

[5] Samir Dev Gupta*, M.C. Srivastava, *"Multilayer Microstrip Antenna Quality Factor Optimization for Bandwidth Enhancement",* Journal Of Engineering Science & Technology (JESTEC), School Of Engineering, Taylor's University, Malaysia, Manuscript ID: EE11_02. The Paper is under review.